Early Results and Fields Tests of an Information Monitoring and Diagnostic System for Commercial Buildings

Phase 2 Project Report

Appendices

September 1998

This document will not be published as an LBNL report but will be included on the project web site (eetd.lbl.gov/EA/IIT/Diag).

TABLE OF CONTENTS

Appendix A. Web-Based Energy Performance Analysis Tools

The Electric Eye web tool is a sophisticated Java-based interface which allows users to access building data over the World Wide Web. It requires a Java-enabled web browser, usually Netscape or Internet Explorer, versions 4.0 or greater. Macintosh computers are not likely to handle the Java script, though they will run the real-time schematics tool (described below). This web tool was developed by Electric Eye, Inc. with the release of the PC version of the Electric Eye software. While it only provides subset of the functions found in the PC and SGI versions of the software, the web tool has served as an excellent demonstration tool for remote monitoring. One large limitation is its current inability to display more than a day of data at a time. It does, however, provide up-to-the-minute data for each point. The current version is currently available only to members of the project team and the project advisory committee; however, we hope to make this, or a modified version, available to the public in the near future.

Plot Manipulation

Some features of the data visualization tool are:

- **Memory**. Your IP address is stored internally and certain preferences will be saved for return visits.
- **Scale**. Change the scale for individual points and save changes for next visit to site by pressing "Save Limits."
- **Box and Zoom**. Select a box with the cursor and zoom in on important data. Press "r" to return to original scale.
- **Calendar**. A calendar window opens with each graph plotted. Select dates from the calendar to view. See **Figure A–1**.

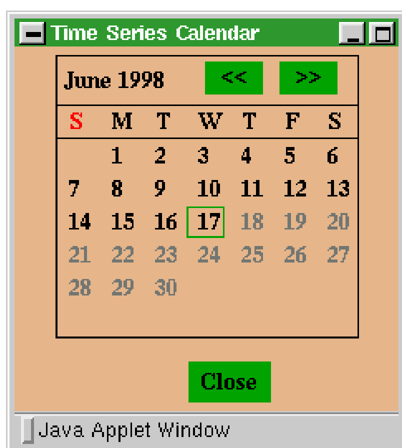


Figure A–1. Calendar Window

Plot Features

The following graphs may be plotted:

1. Time Series Plot

2. XY Cross Plot

   a) Chiller Efficiency kW/ton vs. Chiller Tons
   b) System Efficiency kW/ton vs. System Tons
   c) Tower Approach (OWB - TWRT) vs. Cooling Tower Tons

These plots are part of an initial selection of plots developed for this project. They represent some of the data that is likely to be interesting to building operators. See Appendix B.

Time Series

The time series plot allows you to view a time series for one day of data for up to five points. You may view data on linear or logarithmic scale. **Figure A–2** shows power data for June 17, 1998, at 11:20AM.

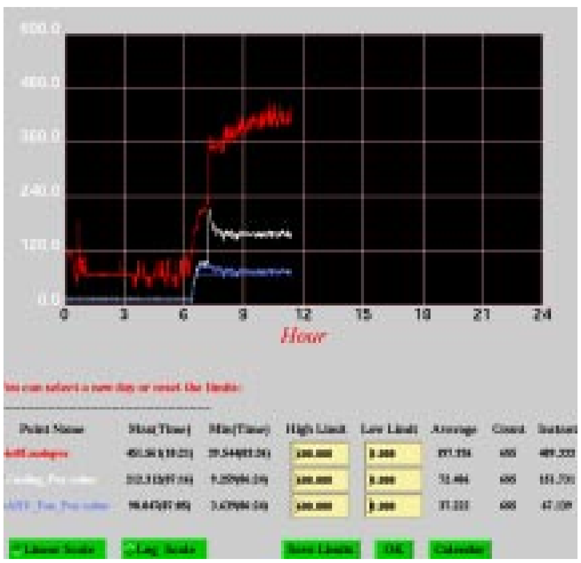


Figure A–2. Time Series

XY Crossplots

The first three XY cross plots are identical in format. System Efficiency kW/ton vs. System Tons, is shown **Figure A–3**.

The data points corresponding to the selected graph should be active upon opening the utility. If you change the points viewed, your changes will be saved, and you will need to re-activate the original points in order to view them.

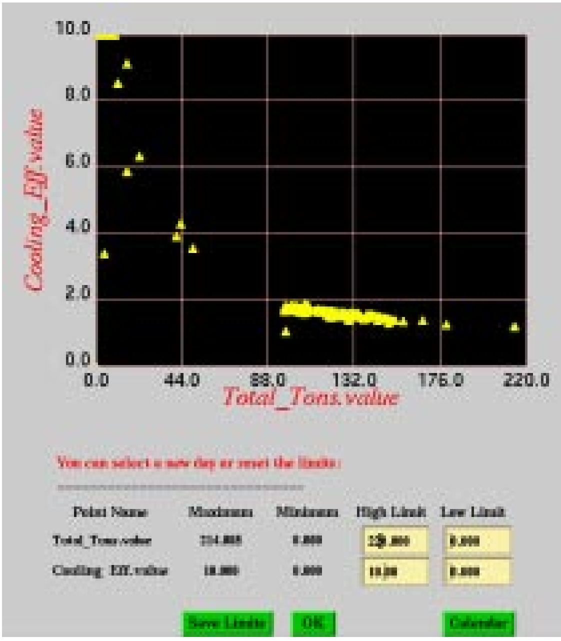


Figure A–3. System Efficiency kW/ton vs. tons

Real-Time Data Schematics

We have recently added to our web-based tools a real-time data schematic viewer. This is also a Java-based tool requiring Netscape or Internet Explorer versions 4.0 or greater. It is housed directly on the Data Acquisition System host. For this reason, we cannot currently release the site to the public due to the heavy burden multiple hits would place on the host.

The web page housing this tool consists solely of a “Start” button, which opens the Java window. The Java window contains six panels, shown in **Figure A–4**. The data shown in the panels is for July 13, 1998, at 11:00AM. The building was in operation; however the cooling system was not in use.

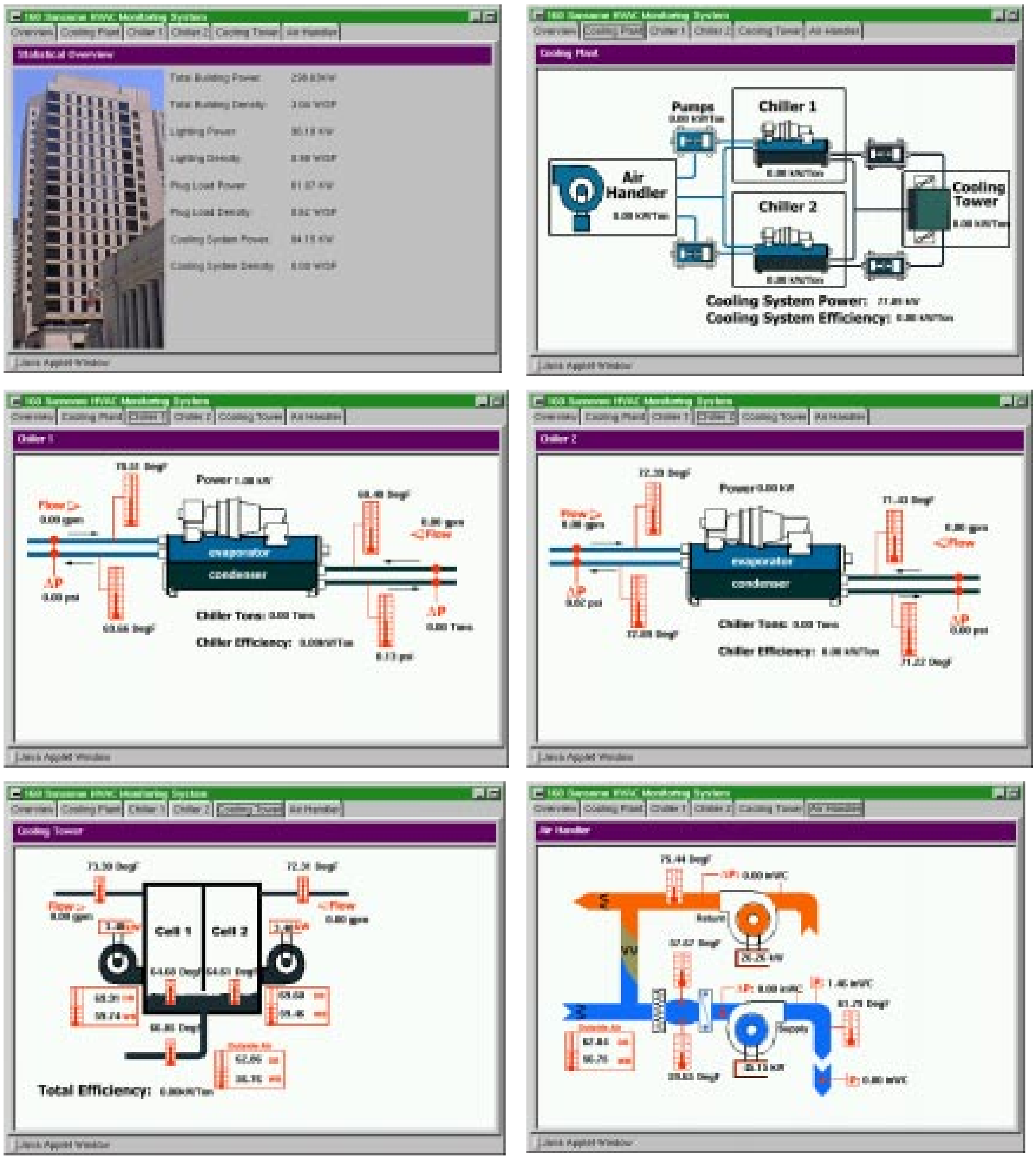


Figure A–4. Real-Time Cooling System Schematics

Appendix B. Diagnostic Plots

We have identified ten diagnostic plots that can be used to analyze building and cooling system performance.

Whole Building Characteristics

1. Whole building electrical power over time

    Plot 1a. 3D carpet plot (power vs day of year vs time of day)
    Plot 1b. 2D plot (power vs time of day) for all days of year
    Plot 1c. 2D plot (power vs time of day) for weekdays only

2. Hourly whole building electrical power vs outdoor temperature

    Plot 2a. All days of year
    Plot 2b. Weekdays only

3. Hourly whole building electrical power vs outdoor temperature, for each 24 hour period

Cooling System Characteristics

4. Hourly cooling system efficiency vs cooling load (tons)
5. Cooling system electrical power vs outdoor temperature

Chiller Characteristics

6. Chiller efficiency vs cooling load (tons)
7. Chiller efficiency over time

    Plot 7a. 3D carpet plot (efficiency vs day of year vs time of day)
    Plot 7b. 2D plot (efficiency vs time of day) for all days of year
    Plot 7c. 2D plot (efficiency vs time of day) for weekdays only

Cooling Tower Characteristics

8. Cooling tower electrical power over time (This plot was not included in the original list of nine plots.)
9. Cooling tower approach temperature vs cooling produced (tons)
10. Cooling tower cooling produced (tons) vs condenser flow

Prototype Description

The plots above have been developed for a prototypical Northern California office building. This building is based on 74 buildings and their average energy use. The prototype is assumed to be located in the Alameda area and has 100,000 square feet of floor space in five stories. The exterior walls have R-22 insulation, and the roof has R-25 insulation. Windows are single-pane, with an average shading coefficient of 0.43 and conductance of about 1.0 Btu/hr/sqft/deg F. About 43% of the exterior wall area and 29% of the building wall and roof envelope is glass. The building is occupied by 365 people (about 274 sqft/person). The maximum lighting demand is assumed to be 1.455 W/sqft, and maximum electrical equipment demand is 0.705 W/sqft. The building is assumed to be almost fully occupied, lighted and equipped between 9am and 5pm weekdays, with tapered loads during night and weekend hours. The building is assumed to generate positive pressure whenever the perimeter fans are on, but allows infiltration of 0.07 cfm/sqft at all other times.

The building is cooled by two electric-powered centrifugal chillers, using two cooling towers with variable-speed fans as heat sinks. The full-load efficiency of the chiller is 0.71 kW/ton. The building is heated by 2 natural gas-fired hot water boilers with a heat input ratio of 1.33, hooked up to a single-zone reheat system.

The building is heated to 69.6° F from 6am to 8pm on weekdays and from 9am to 7pm on weekends from November through February. The building perimeter is cooled to 72.4°F for the rest of the year during the same hourly periods. The building central core (about 57% of the total building floor area) is cooled as needed 24 hours a day, every day. Likewise, the fans run in perimeter areas during the weekday and weekend periods specified above for heating, but the core area fans run all the time.

Whole Building Electrical Power over Time

Whole building power is first normalized by dividing by the total floor area of your building to get a Watts per square foot (W/sqft) value. You can then examine this value over time in different ways to see how it varies. **Figure B–1a** looks at an entire year's worth of whole building power on a three-dimensional "carpet" plot. The turquoise x-axis shows the day of the year, and the yellow z-axis shows the hour of the day, while the vertical y-axis plots the value of whole building power. This plot is able to show the variations in electricity use during the year. From this plot you can make several checks. Are your peak usage values at reasonable levels, and do they show up when you expect them? Are there any unexpected peaks? How about your minimum electricity usage? Does it correspond well with unoccupied hours? Can it be reduced further, or kept lower for longer hours?

The prototypical Northern California Office Building data shown below is an idealized version of a well-controlled building. Power use peaks slightly during the summer (days 180 to 300), when electricity is used to run the chillers, and tapers off in the winter. This annual profile would show more variation in a harsher climate than the Northern California Bay Area's. This building's peak usage of about 4.5 W/sqft occurs during summer afternoons. The power use drops fairly cleanly to a minimum of 1.25 W/sqft at night. There are no unexpected usage patterns in this prototypical 3-D carpet plot.

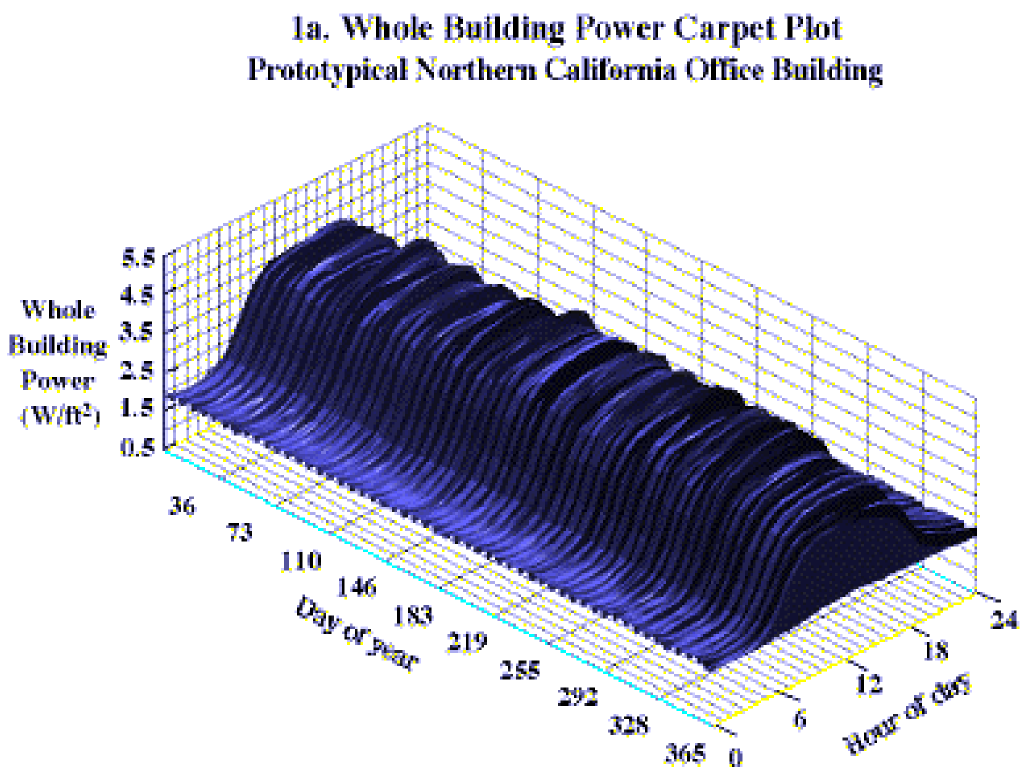


Figure B-1a. Whole Building Power Carpet Plot

Another way to look at the whole building electrical power use is to use a simpler two-dimensional plot of power (y-axis) versus time of day (x-axis). This plot can be viewed in conjunction with, or instead of, the 3-D carpet plot. In **Figure B-1b** below you can see peak usage, baseline usage and the daily load shape more clearly. You can also see clearly a number of low usage days along the bottom of the plot.

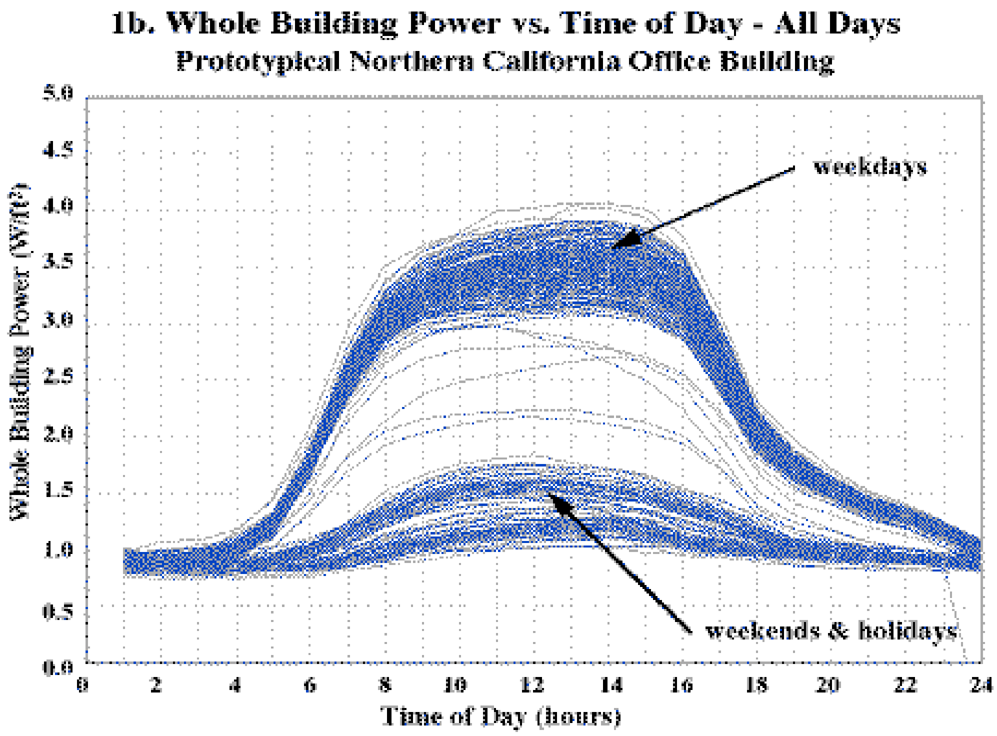


Figure B–1b. Whole Building Power vs. Time of Day – All Days

It's useful to make 2-D plots of only weekdays, weekends, or a specific day of the week to evaluate the its power profile. **Figure B–1c** shows whole building power on weekdays only, but including holidays. Notice that most of the low power days have dropped off the plot, signifying that almost all occupied days use significant power. A plot of weekends & holidays only would also be useful, in order to ensure that power is kept to a minimum when the building is unoccupied.

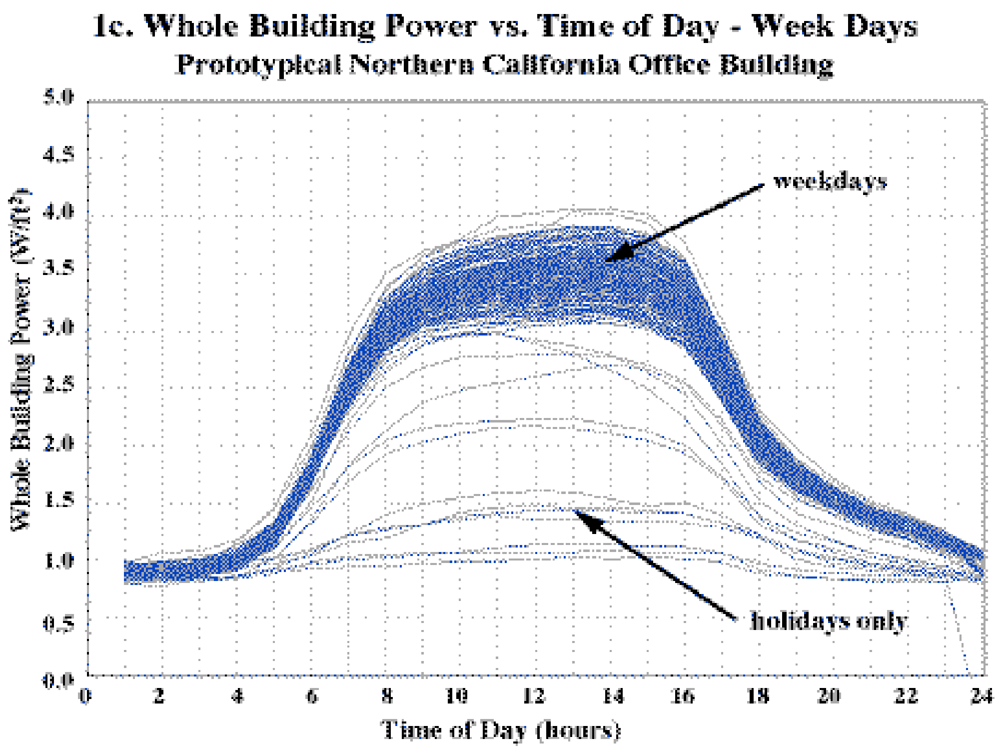


Figure B–1c. Whole Building Power vs. Time of Day – Weekdays

Whole Building Electric Power vs Drybulb Temperature

Looking at whole building power versus the outdoor drybulb temperature is a good way to determine your building's dependence on weather conditions. (Remember to normalize your power use by floor area, to plot W/sqft). If your building is electrically cooled but not electrically heated, as is the case with our prototypical building, you should see your maximum power correspond to the hottest drybulb temperatures. If you use electric heaters, you would expect a more U-shaped curve, with high power use at both low temperatures and high temperatures.

In **Figure B–2a**, there are three data "clumps". The lowest clump occurs when no chillers are running to cool the building. The middle clump shows power use when one chiller is on, and the highest clump shows power use when both chillers are in use. Note the increasing slope of each clump, defining the increasing dependency of power use on temperature as more cooling equipment is used. Watch out for stray data points, or small clumps points in unexpected locations.

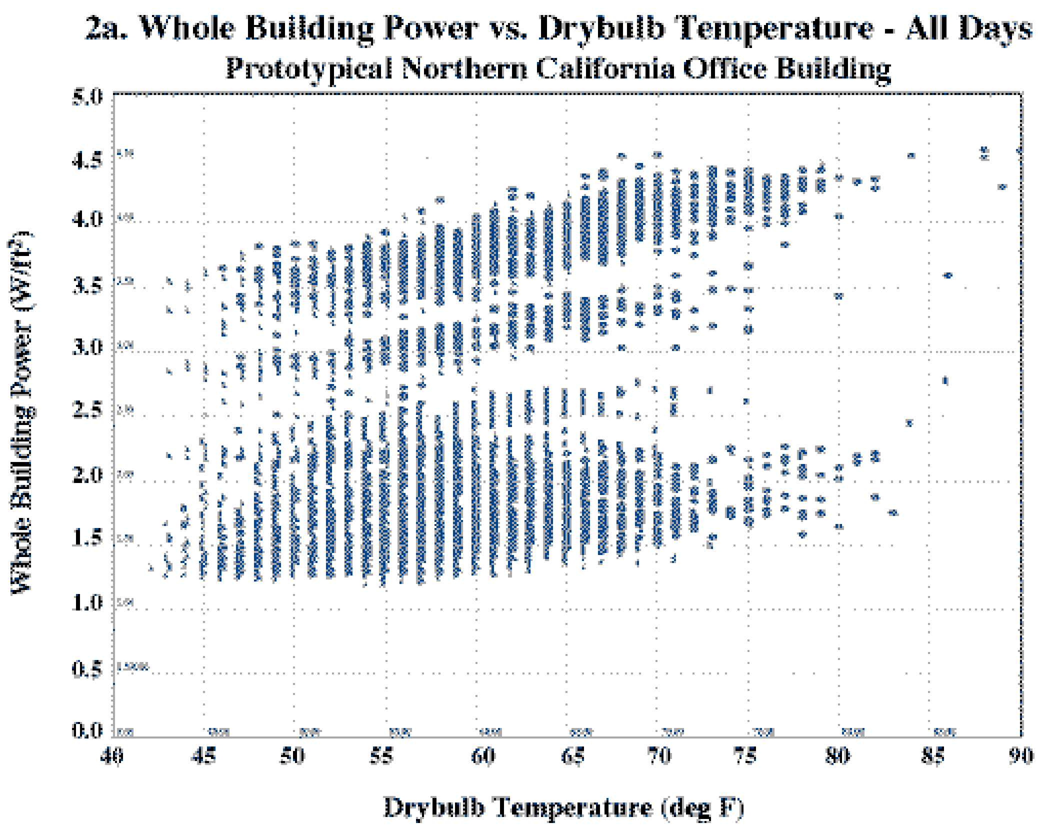


Figure B-2a. Whole Building Power vs. Drybulb Temperature – All Days

One can also look at specific days, weekdays only, or weekends only. **Figure B–2b** below of the Northern California prototype looks at only weekdays. The most noticeable difference between the weekday plot and the all day plot is there are fewer low-power use days.

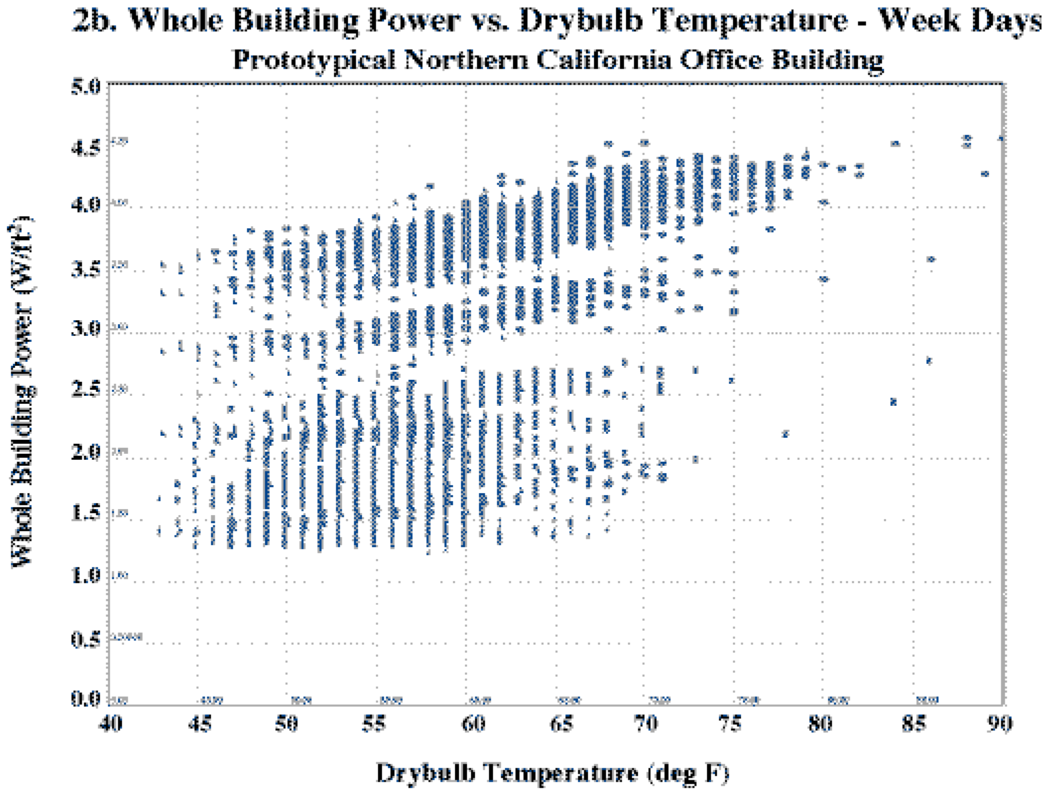


Figure B-2b. Whole Building Power vs. Drybulb Temperature – Weekdays

Whole Building Power vs Outdoor Temperature, for each 24 hour period

Another meaningful way to examine whole building power is to look at each hour of the day separately. This way you can clearly see hourly trends in power use, and quickly determine where your energy use might be lowered. **Figure B–3** below is a sample plot from the prototypical Northern California building of power versus outdoor drybulb temperature. There are a number of things to be observed here.

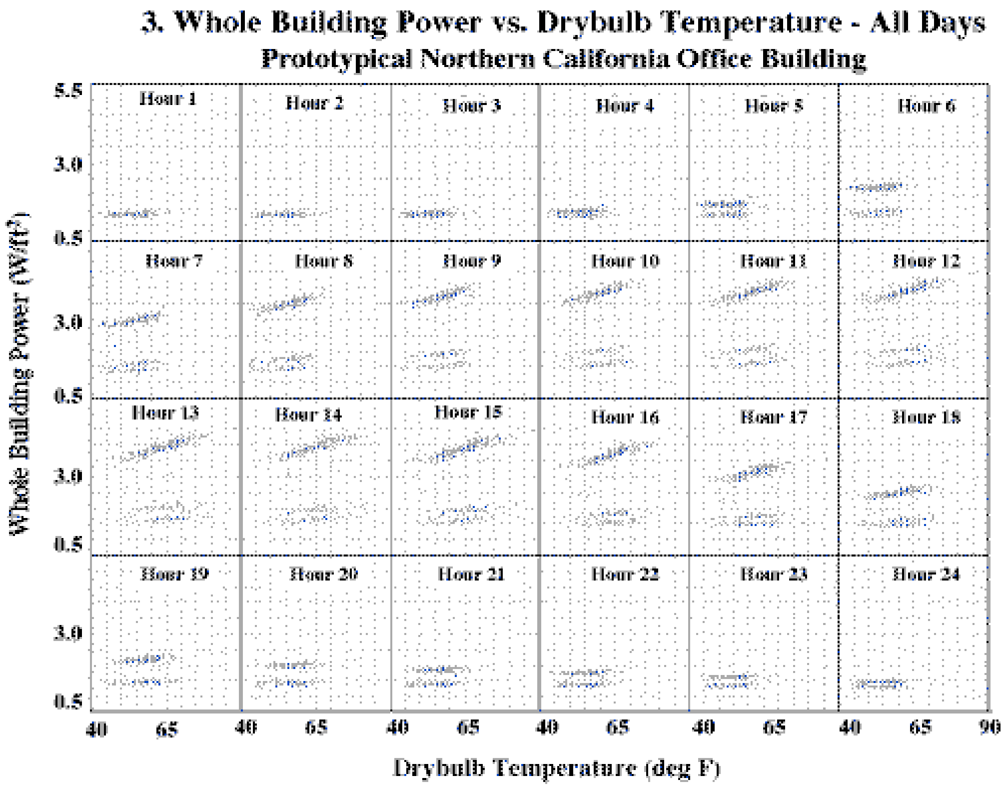


Figure B–3. Whole Building Power vs. Drybulb Temperature – All Days

First, you can see that the minimum energy use occurs during the nighttime and early morning hours, when the building is unoccupied. The flat nighttime load shape shows that little if any cooling is used at night. During hours 5 and 6 you can see power use separate into two lines, the lower line for unoccupied days and the higher for occupied days. The power increases during hours 5 and 6 occur as lights and appliances begin to come on in the building. Note that the power use of these non-cooling related appliances is generally not sensitive to outdoor temperature, as shown by their non-sloping appearance. At hour 7, power use not only rises further, but starts to become temperature dependent. This signals that fans and/or chillers are now used to cool the building. Also at hour 7, the lower unoccupied line begins to split into 2 separate lines as the building core area may need some cooling on some of the minimally occupied days.

Through the morning and into the afternoon, the power versus temperature curves spread further apart as the power used for lights, appliances, cooling and ventilation peaks. At hour 15 the power use begins to taper off, and the curves slowly coalesce as the end of the day is reached.

Cooling System Efficiency versus Cooling Load

A plot of your cooling system efficiency versus the delivered load is a useful tool for system analysis. This plot can be compared to theoretical efficiency curves for your system. It can also be monitored over time to check for degradation of your cooling system performance. Cooling system performance is dominated by the chiller, so the shape of this curve should look a lot like your chiller performance curve. Overall system efficiency should lie somewhere between a low 2.0 kW/ton and a high 0.7 kW/ton, with newer systems having higher efficiencies. **Figure B–4** shows the efficiency curve for our prototypical building. This idealized curve is very well defined. An actual curve will have more scattering of points. But every curve will have an area where the curve generally flattens out and the optimal efficiencies are reached. The curve below flattens out above 30% of the maximum load. To maximize system efficiency you want to run your system at these loads as much as possible, and avoid the lower-load, steeper part of the curve where the system is less efficient.

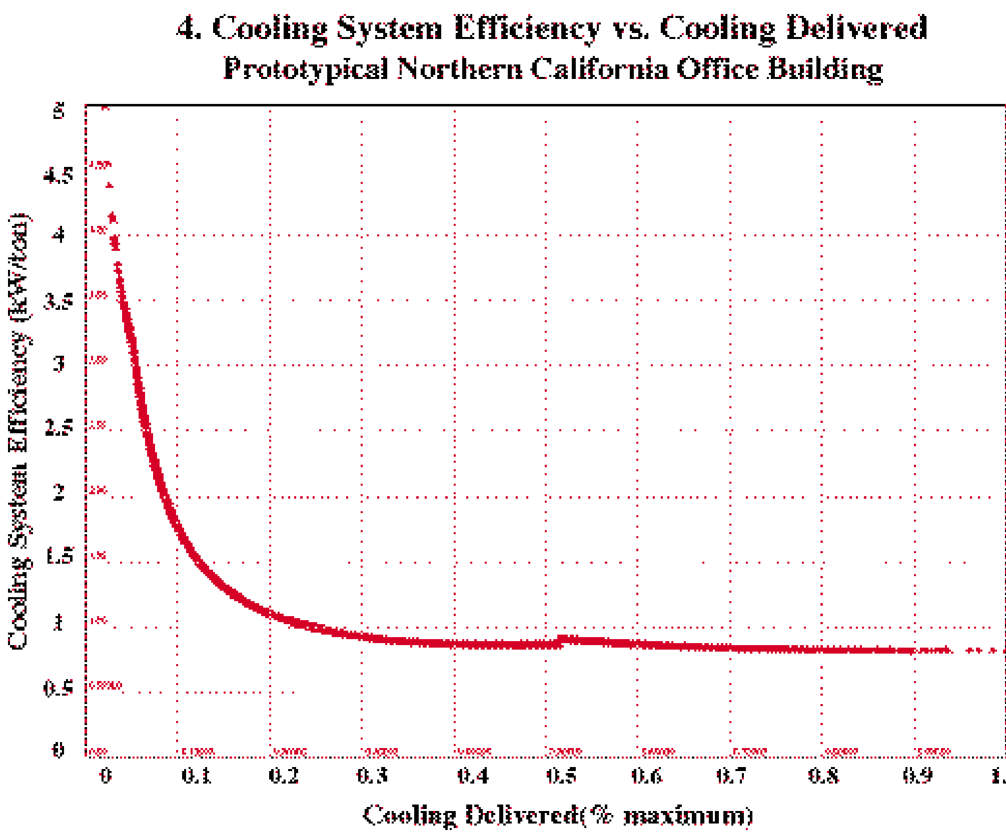


Figure B–4. Cooling System Efficiency vs. Cooling Delivered

Comparison of your efficiency curve to system specifications or to historical performance of your system can be used to find many problems. Your efficiency curve may not be as high as the specs, or as high as it was a year ago. This may be caused by a number of things, including:

- Design flaws
- System changes (such as cooling tower down time)
- Poor water flow characteristics (perhaps you need multiple chillers)

- Component malfunctions (like condenser fan cycling)
- Fouling of chiller tubes
- Loss of refrigerant charge
- Poor full-load or part-load performance (may be related to weather conditions)
- Over- or under-sizing of components

Loss of efficiency is not the only thing to look for on your cooling system efficiency curve. You also want to look at where you're operating on this curve, and for how long. Watch out for:

- Excessive on time
- Short cycling
- Heavy system use at low efficiencies.

Cooling System Electrical Power versus Outdoor Drybulb Temperature

Another interesting plot is cooling system power versus the hourly outdoor drybulb temperature. This curve shows the temperature dependence, with power use increasing with outdoor temperature. **Figure B–5** below, for our prototypical Northern California office building, also clearly shows two lines of system operation. The lower line shows operation with only one chiller in operation, and the upper line is when both chillers are running.

Cooling system power is highly dependent on outdoor temperature. But it also depends on building loads, such as solar loads, lighting and appliance use, and people. In the prototypical plot below there is quite a bit of load scatter at any given outdoor temperature. In general, the load is met by a single chiller at low outdoor temperatures, and by both chillers at high outdoor temperatures. But at non-extreme temperatures one or both chillers may be needed to meet the building loads.

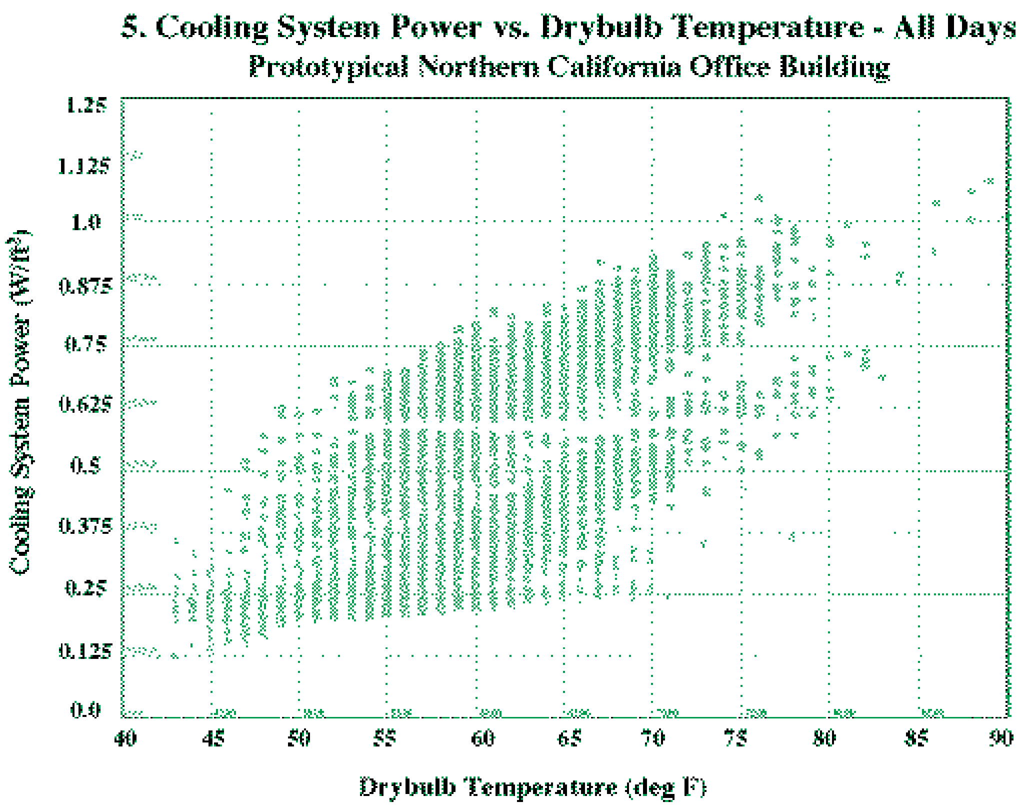


Figure B–5. Cooling System Power vs. Drybulb Temperature – All Days

Chiller Efficiency versus Chiller Cooling Load

It is valuable to track of the efficiency of your chillers, either through continuous monitoring or by making periodic checks of performance for various loads. It is useful to compare their performance to the manufacturer's specifications, as well as to track performance over the chiller's lifetime. **Figure B–6** shows chiller efficiency in kW/ton versus the cooling load in tons for our prototypical Northern California office building. Note that this curve reaches an optimum efficiency plateau at a load of about 100 tons. For best overall performance, you want to operate your chiller at or above this level. The newest, most efficient chillers plateau at full-load efficiencies of 0.6 kW/ton or better. Older, less efficient chillers may have full-load ratings of 0.9 to 1.0 kW/ton or higher.

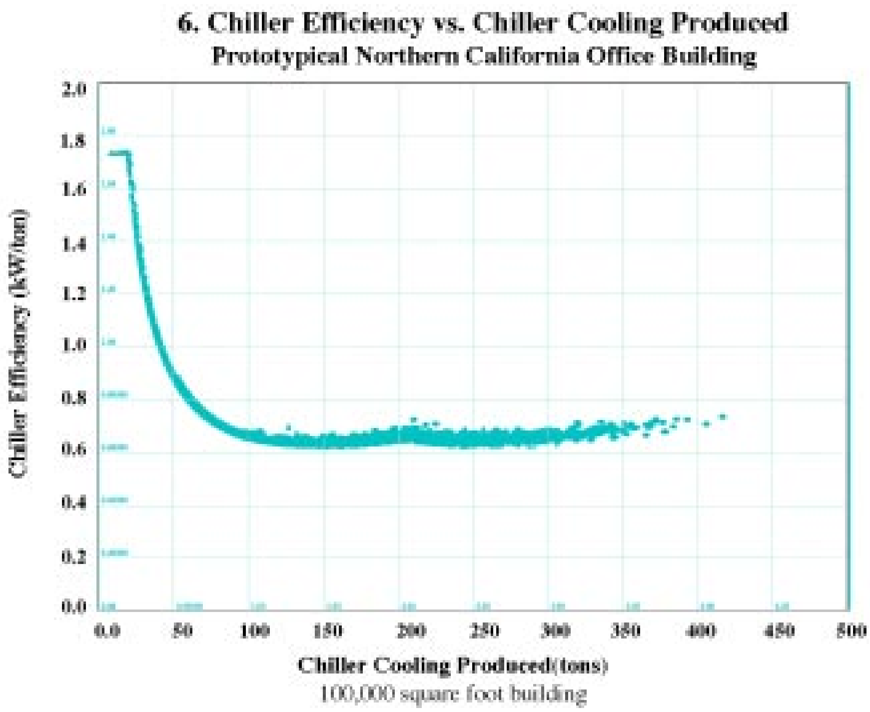


Figure B–6. Chiller Efficiency vs. Chiller Cooling Produced

Loss of efficiency over time may be caused by:

- Poor water flow through the chiller
- Fouling of the chiller
- Lack of refrigerant charge
- Poor efficiency on part of the curve may be due to low loading conditions during mild weather

In addition, watch out for how often your chiller is being used, and where that usage is on the efficiency curve:

- Excessive on time at full-load
- Chiller may be undersized
- Delivery system may not be working properly
- Setpoints or control schedules may not be optimal

Frequent cycling behavior and/or heavy part-load use

- Chiller may be oversized
- Temperature gauges or thermostats may be malfunctioning
- Control schedules may not be optimal.

Chiller Efficiency over Time

Looking at chiller efficiency over time will help you to see if you're using your chiller effectively. Efficiency can be plotted on a three-dimensional carpet plot (efficiency vs day of year vs time of day) or on a simpler two-dimensional plot of efficiency vs time of day. Either plot can be used to pinpoint where chiller efficiencies are lower than expected. These plots can be used to fine tune your operating schedules, or to trouble shoot for chiller problems.

Figure B–7a shows the 3-D carpet plot of efficiency for our prototypical Northern California office building. You can see the best efficiency is achieved in the middle of the day when the chiller is running at full load. Seasonal variations can also be observed. The full load "channel" is wider during the summer months, when chiller loads are higher for a longer part of the day. Part-load efficiencies are also better on the "shoulders" during the summer months. During the winter, shorter periods of full-load operation and longer periods of less efficient, part-load operation are observed.

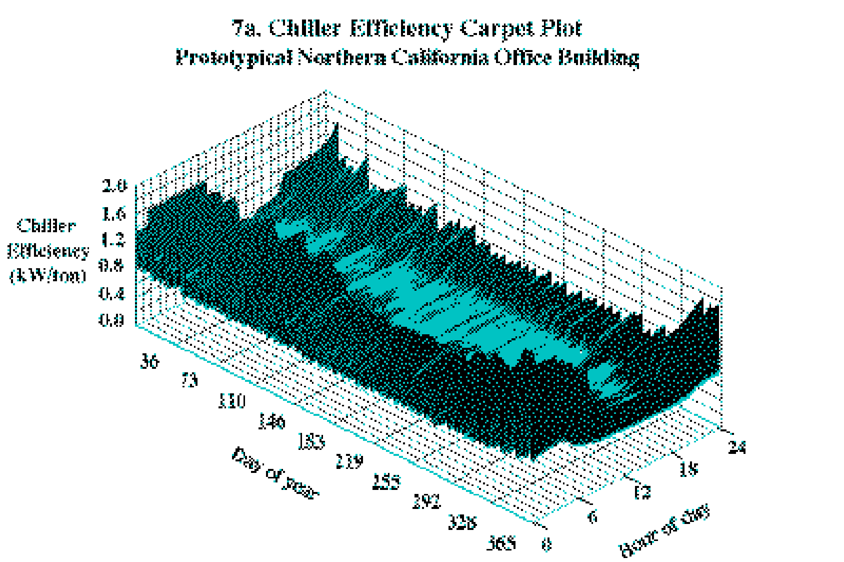


Figure B–7a. Chiller Efficiency Carpet Plot

The 2-D plot of the prototypical Northern California office building is shown in **Figure B–7b** for all days of operation for a year, then in **Figure B–7c** for weekdays only. In these two plots you can see that weekend/weekday operation is slightly different. On weekdays chiller operation begins at 5 or 6 am, while on weekends operation doesn't begin until 8 am. Weekends are less likely to reach the most efficient full-load conditions, since only the core of the building is being cooled and there are lower building loads.

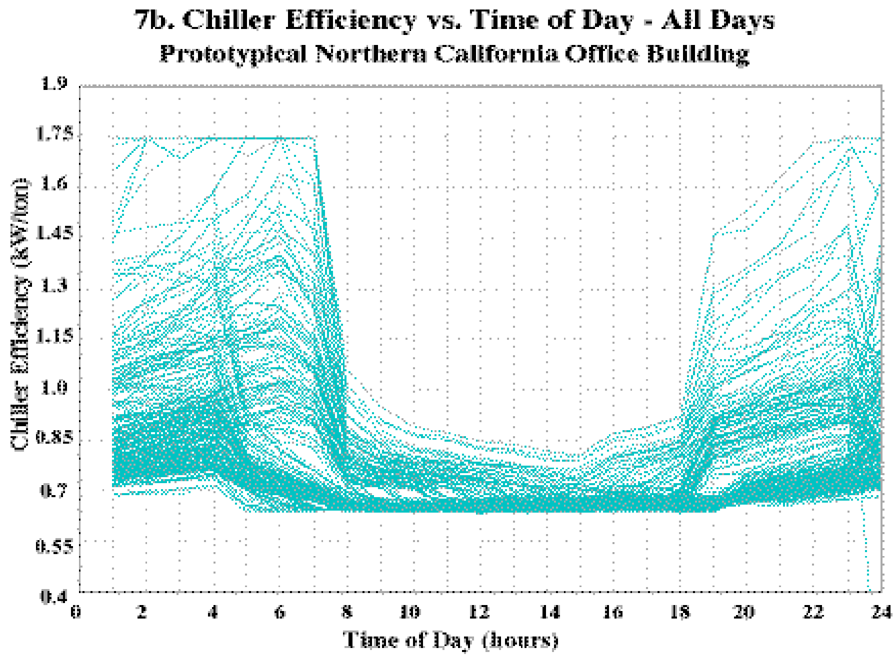


Figure B–7b. Chiller Efficiency vs. Time of Day –All Days

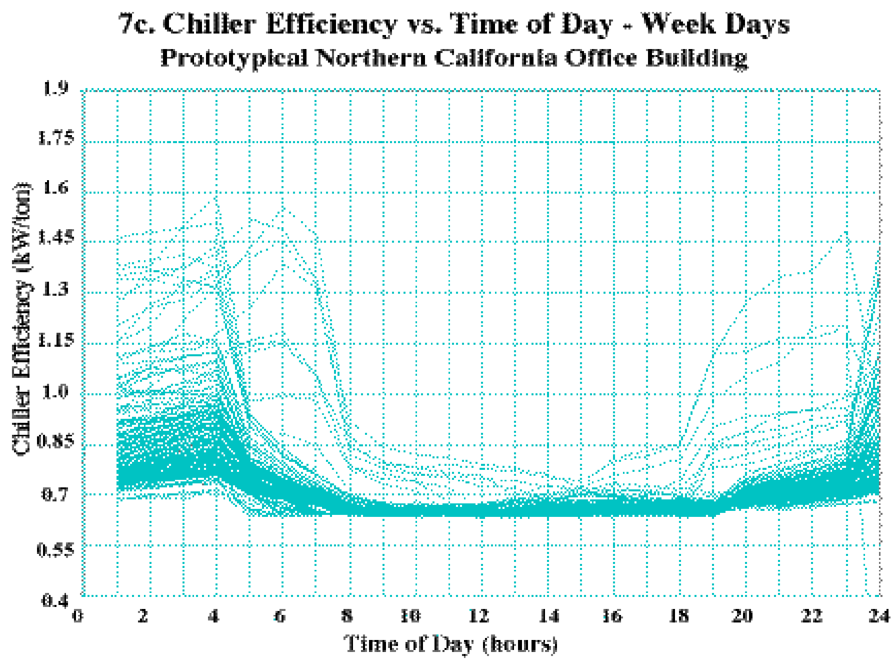


Figure B–7c. Chiller Efficiency vs. Time of Day – Weekdays

Cooling Tower Power over Time

Looking at cooling tower power over time will help you to see when you're using your cooling tower. This plot can be a three-dimensional carpet plot (power vs day of year vs time of day) or a simpler two-dimensional plot of power vs time of day. These plots can be used to fine tune your operating schedules, or to trouble shoot for cooling tower problems.

Figure B–8 shows the 2-D plot of cooling tower power for all days of the year in our prototypical Northern California office building. Looking at this plot together with plots of chiller power use can ensure that the cooling tower is always working when the chiller is running. The prototypical cooling tower for our building runs at two flow levels, one using about 0.8 kilowatts over a full hour of run time and the other using about 1.6 kilowatts to pump double the flow level. If the cooling tower was undersized, as is common, this plot would show significantly more operation time at the 1.8 kilowatt level.

An undersized cooling tower can seriously impact the chiller efficiencies! A too-small cooling tower will deliver warmer than necessary water to the condenser, not allowing the chiller to release as much heat and worsening the chiller's efficiency. This problem will degrade chiller operations when you most need optimal performance - on hot days and during afternoon load and energy-rate peaks.

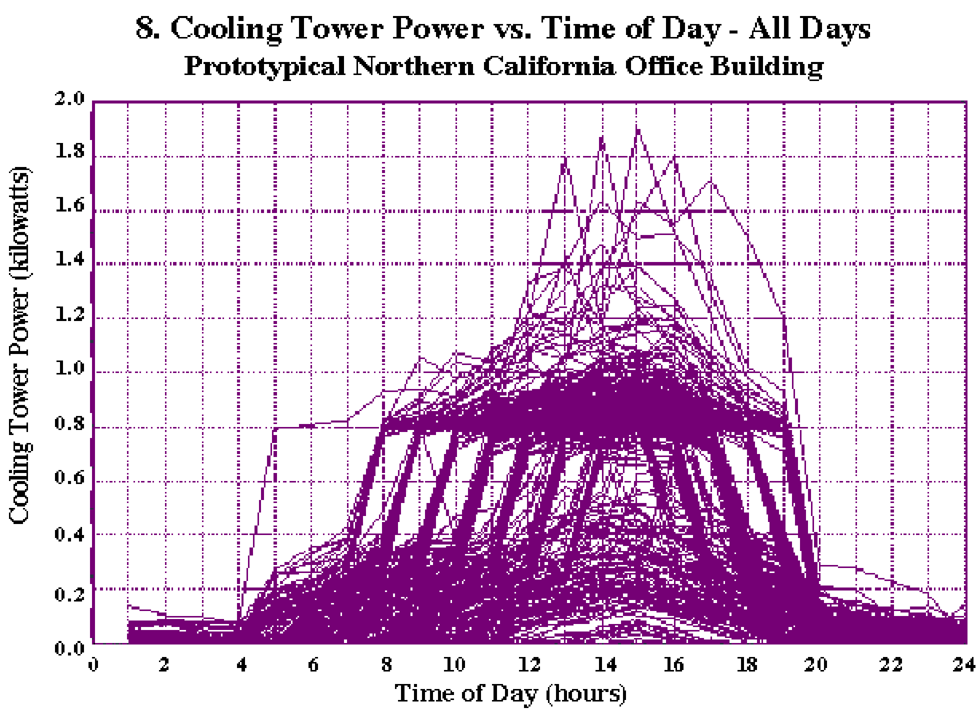


Figure B–8. Cooling Tower Power vs. Time of Day – All Days

Cooling Tower Approach Temperature vs Cooling Produced

Another useful plot for evaluating cooling tower performance is the cooling tower approach temperature versus the tons of cooling produced. The approach temperature is defined as the condenser water supply (or cooling tower exit) temperature minus the wet bulb temperature. As more energy is extracted from the cooling tower flows, the condenser water supply temperature "approaches" its limit of the wet bulb temperature, and the approach temperature becomes smaller.

Figure B–9 is a 2-D plot of cooling tower approach versus the cooling tower cooling produced for all days of the year in our prototypical Northern California office building. The approach temperature is reduced as more cooling is produced. This plot can be watched to see if the approach temperature is increasing over time at different tonnage levels - an indication of fouling of the cooling tower and a signal to clean it. More efficient cooling tower operation can deliver cooler water to the condenser of the chiller, for better chiller efficiencies and lower energy use.

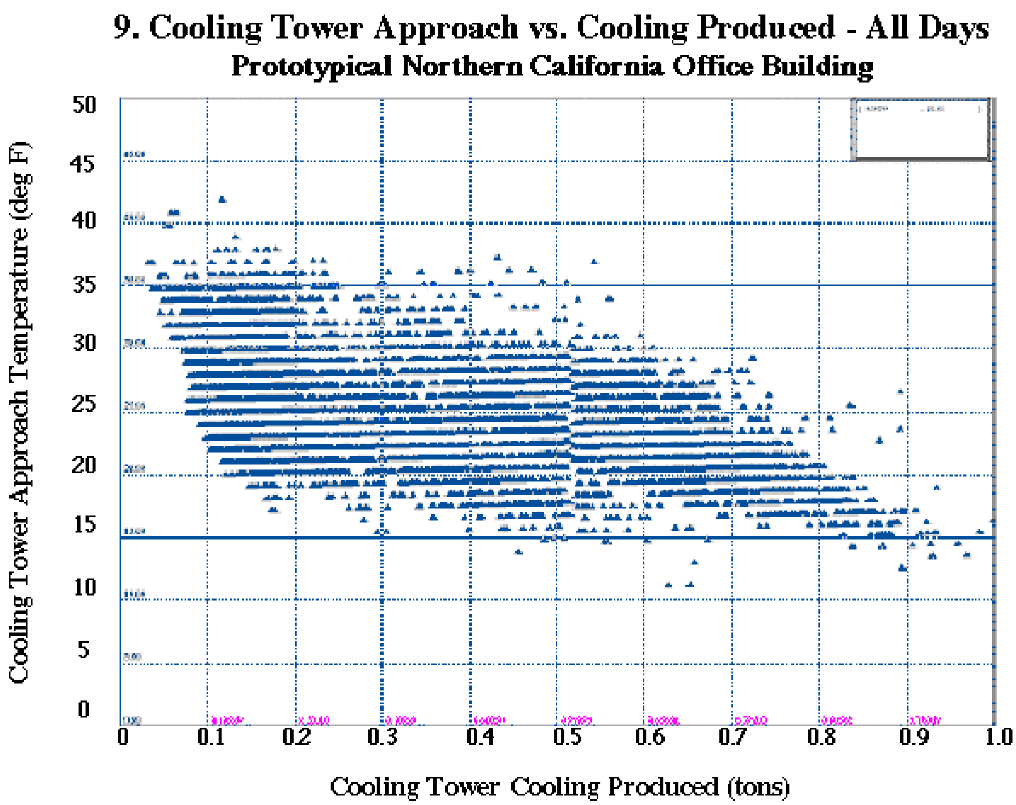


Figure B–9. Cooling Tower Approach vs. Cooling Produces – All Days

Cooling Tower Cooling Produced vs Condenser Flow

A plot of cooling produced versus condenser flow allows you to keep track of the amount of flow through the cooling tower and how much cooling is produced from the cooling tower alone.

Figure B–10 is a 2-D plot of cooling tower cooling produced versus the condenser flow for all days of the year in our prototypical Northern California office building. This theoretical cooling tower runs at two flow levels, 190 or 380 gallons per minute. Since this is a theoretical building, the condenser flows remain exactly the same all year, with no flow reduction due to fouling of the piping or the cooling tower, and no piping leaks.

In an actual building, you must watch for flow reductions over time as the cooling tower becomes clogged and dirty. You must also watch for higher than normal flows through the cooling tower, which could indicate problems with pump operations.

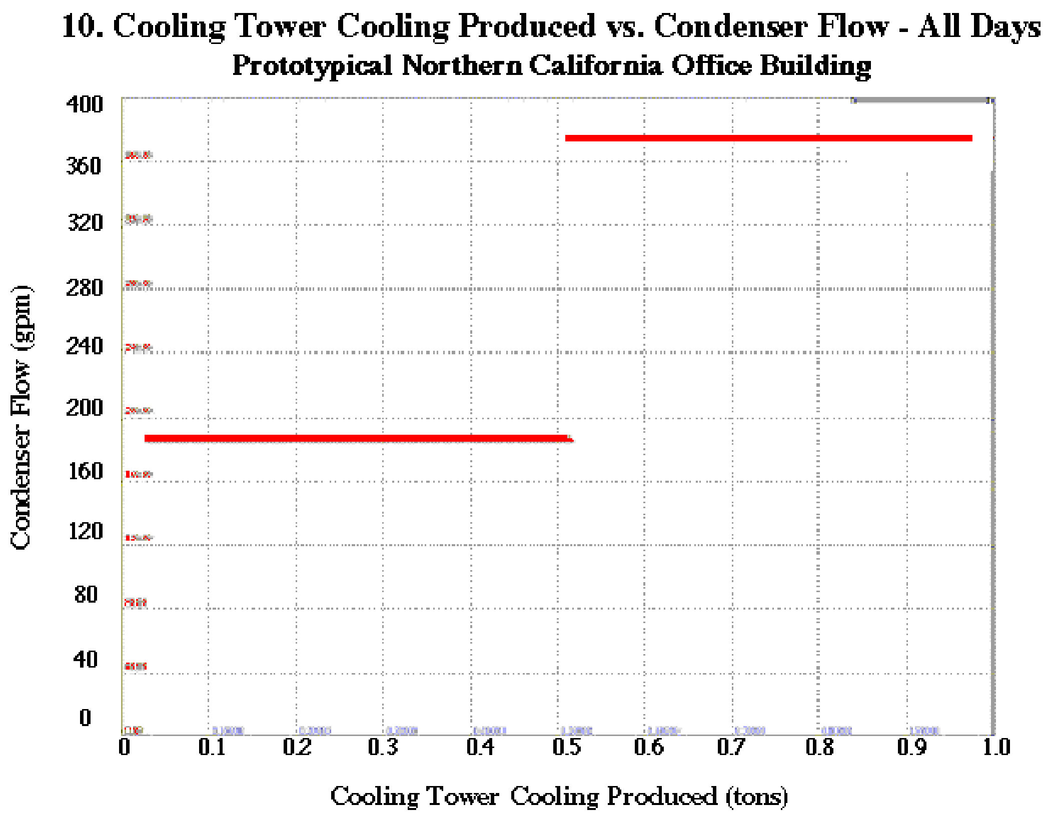


Figure B–10. Cooling Tower Cooling Produced vs. Condenser Flow – All Days

Appendix C. IMDS Points, Sensor, and Data Production Systems

Complete Point List

IMDS Point List -- 160 Sansome

	Point Description	Name	Type
1	Building Lighting Riser One Power	io05.lgtr1pwr	Physical
2	Building Lighting Riser Two Power	io05lgtr2pwr	Physical
3	Building Main Power	io05.mainpwr	Physical
4	Building Plug Load Riser One Power	io05.plgr1pwr	Physical
5	Building Plug Load Riser Two Power	io05.plgr2pwr	Physical
6	Building Watts per Square Foot	main_pwr_wsf	Calculated
7	Chilled Water Efficiency (kW/ton)	Ch1_kWpton	Calculated
8	Chilled Water Efficiency (kW/ton)	Ch2_kWpton	Calculated
9	Chilled Water Flow Chiller 2	Ch2_Flw	Calculated
10	Chilled Water Load (tons)	Ch1_Tons	Calculated
11	Chilled Water Load (tons)	Ch2_Tons	Calculated
12	Chilled Water Pump One Differential	CHWP1_DPres	Physical
13	Chilled Water Pump One Power	CHWP1_Pwr	Physical
14	Chilled Water Pump Two Differential	CHW2_DPres	Physical
15	Chilled Water Pump Two Power	CHWP2_Pwr	Physical
16	Chilled Water Second Floor Cooling Coil	L2_CHWR_Flw	Physical
17	Chilled Water Temperature Difference *	CHW1_dt	Calculated
18	Chilled Water Temperature Difference *	CHW2_dt	Calculated
19	Chiller One Chilled Water Flow	CHWR1_Flw	Physical
20	Chiller One Chilled Water Return	CHWR1_Temp	Physical
21	Chiller One Chilled Water Supply	CHWS1_Temp	Physical
22	Chiller One Condenser Differential Pressure	CW1_DPres	Physical
23	Chiller One Condenser Water Flow	CWR1_Flw	Physical
24	Chiller One Condenser Water Return	CWR1_Temp	Physical
25	Chiller One Condenser Water Supply	CWS1_Temp	Physical
26	Chiller One Evaporator Differential Pressure	CHW1_DPres	Physical
27	Chiller One Power	Ch1_Pwr	Physical
28	Chiller Two Chilled Water Return	io03.chwr2tmp	Physical
29	Chiller Two Chilled Water Supply	io03.chwr1tmp	Physical
30	Chiller Two Condenser Differential Pressure	CW2_DPres	Physical
31	Chiller Two Condenser Water Flow	CWR2_Flw	Physical
32	Chiller Two Condenser Water Return	io03.cwr2tmp	Physical
33	Chiller Two Condenser Water Supply	io03.cws2tmp	Physical
34	Chiller Two Evaporator Differential Pressure	CHW2_DPres	Physical
35	Chiller Two Power	Ch2_Pwr	Physical
36	Condenser 1 Water Efficiency *	Ch1CW_kWpto	Calculated
37	Condenser 2 Water Efficiency *	Ch2_CWkWpto	Calculated
38	Condenser load (tons)	Ch1CW_Tons	Calculated
39	Condenser load (tons)	Ch2CW_Tons	Calculated
40	Condenser Water Pump One Power	CWP1_Pwr	Physical
41	Condenser Water Pump Two Power	CWP2_Pwr	Physical
42	Condenser Water Temperature Difference *	CW1_dt	Calculated
43	Condenser Water Temperature Difference *	CW2_dt	Calculated
44	Conditioned Air Fan Efficiency	Fan_Eff	Calculated
45	Cooling Load Watts per Square Foot	cooling_wsf	Calculated
46	Cooling Tower Cell One Basin Temperature	CT1_Bsn_Temp	Physical
47	Cooling Tower Cell Two Basin Temperature	CT2_Bsn_Temp	Physical
48	Cooling Tower FAN #1 Power	CT1_Pwr	Physical

IMDS Point List -- 160 Sansome

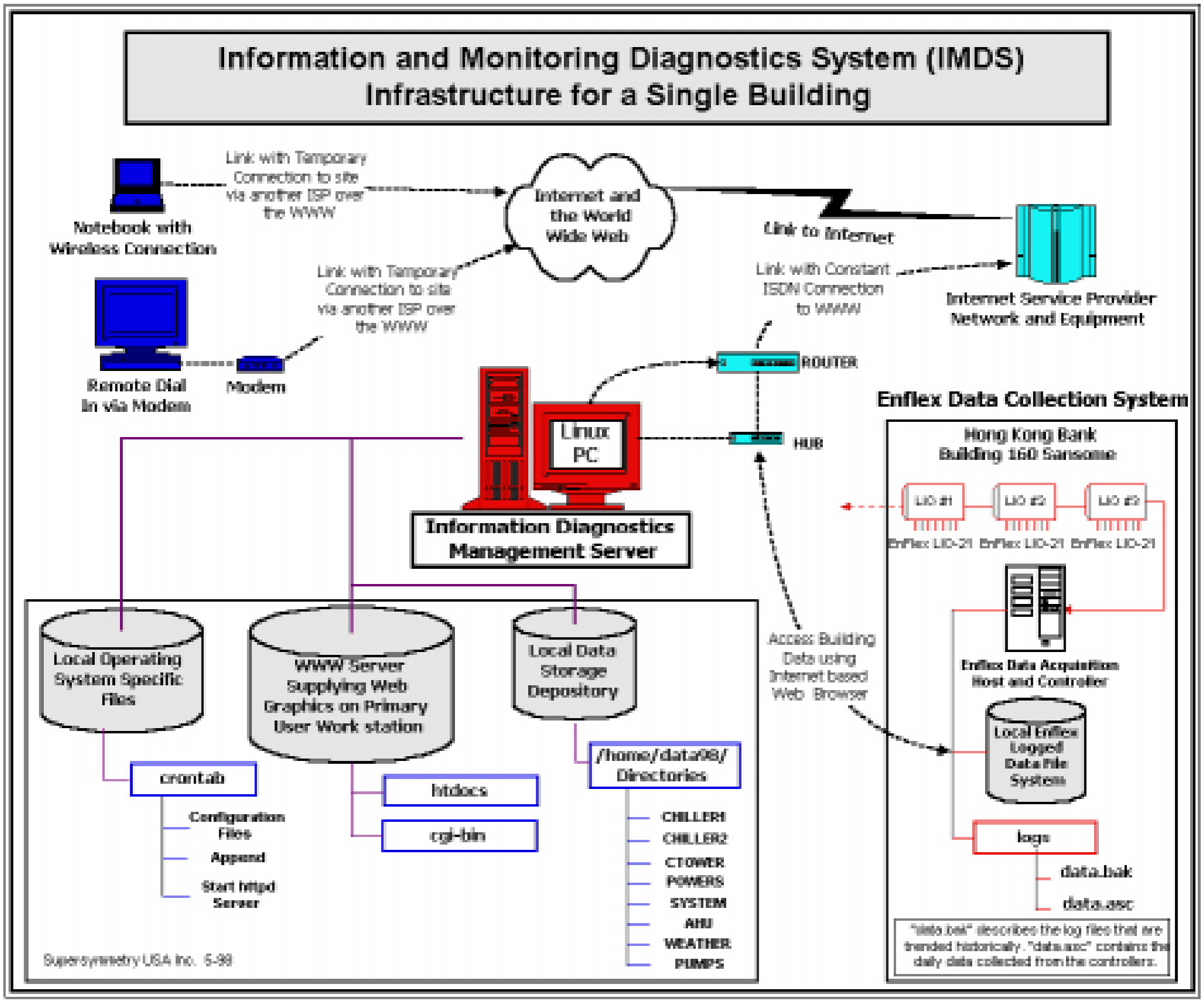
	Point Description	**Name**	**Type**
49	Cooling Tower FAN #2 Power	CT2_Pwr	Physical
50	Cooling Tower Mixed Basin Temperature	CTMxd_Bsn_Te	Physical
51	Cooling Tower One Fan Inlet Dry Bulb	io04.ct1db	Physical
52	Cooling Tower One Fan Inlet Wet Bulb	io04.ct1wb	Physical
53	Cooling Tower One Supply Water	CTSW1_Temp	Physical
54	Cooling Tower Pump One Differential	CWP1_DPres	Physical
55	Cooling Tower Pump Two Differential	CWP2_DPres	Physical
56	Cooling Tower Two Fan Inlet Dry Bulb	io04.ct2db	Physical
57	Cooling Tower Two Fan Inlet Wet Bulb	io04.ct2wb	Physical
58	Cooling Tower Two Supply Water	CTSW2_Temp	Physical
59	Floor Static Pressure	Flr_Space_Stat	Physical
60	Lighting Load Riser Power	Light_Riser_Pw	Calculated
61	Lighting Load Watts per Square Foot	light_wsf	Calculated
62	Mixed Air Ambient Temperature (East)	io01.ma2.temp	Physical
63	Mixed Air Ambient Temperature (West)	io01.ma1.temp	Physical
64	Mixed Air Temperature Average	MA_AveDB_Te	Calculated
65	Outdoor Ambient Air -- Dry Bulb	OA_DB_Temp	Physical
66	Outdoor Ambient Air -- Wet Bulb	OA_WB_Temp	Physical
67	Plug Load Riser Power	Plug_Riser_Pwr	Calculated
68	Plug Load Watts per Square Foot	plug_wsf	Calculated
69	Pump Efficiency	Pump_Eff	Calculated
70	Return Air Ambient Temperature	RA_DB_Temp	Physical
71	Return Air Fan Discharge Static Pressure	RA_Stat_Pres	Physical
72	Return Air Fan Power	RA_Pwr	Physical
73	Supply Air Ambient Temperature	SA_DB_Temp	Physical
74	Supply Air Discharge Static Pressure at	L4_Stat_Pres	Physical
75	Supply Air Fan Discharge Static Pressure	SA_Stat_Pres	Physical
76	Supply Air Fan Power	SA_Pwr	Physical
77	Total Chilled Water Flow Return from Main	CHWR_Main_F	Physical
78	Total Conditioned Air Fan Energy	AHU_Fan_Pwr	Calculated
79	Total Cooling System Efficiency	Cooling_Eff	Calculated
80	Total Cooling System Energy	Cooling_Pwr	Calculated
81	Total Cooling System Flow	CHW_Flw	Calculated
82	Total Power (Chillers)	Total_Pwr	Calculated
83	Total Pump Energy	Pump_Pwr	Calculated
84	Total System Condenser Load	Tot_CWTons	Calculated
85	Total System Cooling Load	Tot_Tons	Calculated
86	Total System Static Pressure	Tot_System_Sta	Calculated
87	Total Tower Fan Energy	CT_Fans_Pwr	Calculated
88	Tower Approach	CT_Approach	Calculated
89	Tower Efficiency	CT_Eff	Calculated
90	Tower Water Return Temperature	CTRW_Temp	Physical

* Not trended

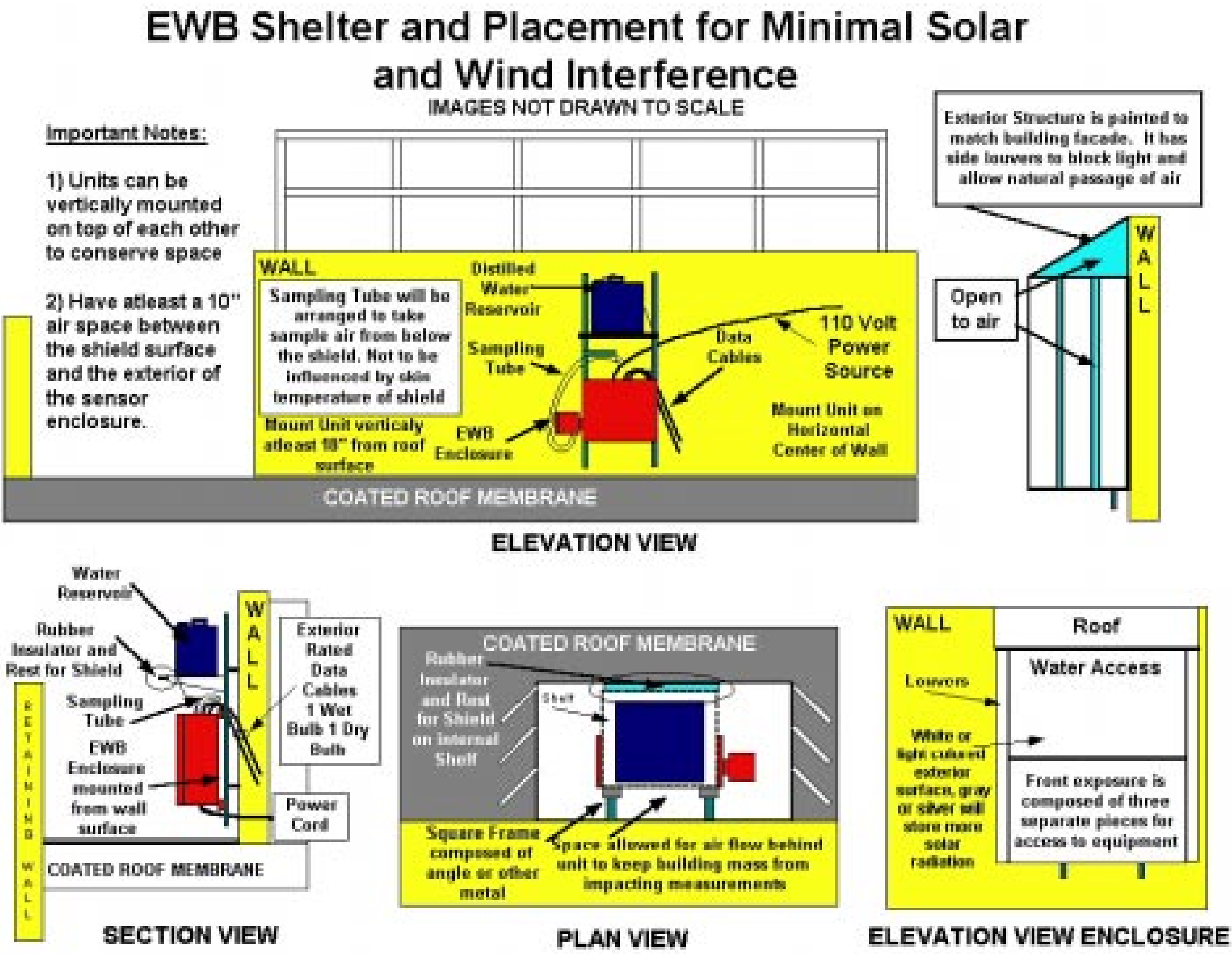
Formulas for Calculated Points

	Point Description	Point Name	Expected Value	Formula
Chiller 1				
1	Chilled Water Temperature Difference	CHW1_dt	0 to 20 F	CHWR1_Temp-CHWS1_Temp
2	Condenser Water Temperature Difference	CW1_dt	0 to 20 F	CWR1_Temp - CWS1_Temp
3	Chilled Water Load (tons)	Ch1_Tons	0 to 225 tons	(CHWR1_Flw x CHW1_dt)/24
4	Condenser load (tons)	Ch1CW_Tons	0 to 225 tons	(CWR1_Flw x CW1_dt)/24
5	Condenser Water Efficiency	Ch1CW_kWpton	0 to 3.0 kW/ton	Ch1_Pwr/Ch1CW_tons
6	Chilled Water Efficiency (kW/ton)	Ch1_kWpton	0 to 3.0 kW/ton	Ch1_Pwr/Ch1_Tons
Chiller 2				
7	Chilled Water Temperature Difference	CHW2_dt	0 to 20 F	io03.chwr2tmp-io03.chws2tmp
8	Condenser Water Temperature Difference	CW2_dt	0 to 20 F	io03.cwr2tmp - io03.cws2tmp
9	Condenser load (tons)	Ch2CW_Tons	0 to 225 tons	(CWR2_Flw x CW2_dt)/24
10	Chilled Water Load (tons)	Ch2_Tons	0 to 225 tons	(Ch2_Flw x CHW2_dt)/ 24
11	Chilled Water Flow Chiller 2	Ch2_Flw	0 to 500 gpm	CHWR_Main_Flw+L2_CHWR_Flw - CHWR1_Flw
12	Condenser Water Efficiency	Ch2_CWkWpton	0 to 3.0 kW/ton	Ch2_Pwr/Ch2CW_tons
13	Chilled Water Efficiency (kW/ton)	Ch2_kWpton	0 to 3.0 kW/ton	Ch2_Pwr/Ch2_Tons
Cooling Tower				
14	Tower Approach	CT_Approach	0 to 20 F	OA_WB_Temp-CTRW_Temp
15	Total Tower Fan Energy	CT_Fans_Pwr	0 to 30 kW	CT1_Pwr + CT2_Pwr
16	Tower Efficiency	CT_Eff	0 to .2 kW/ton	CT_Fans_Pwr/Tot_Tons
AHU				
17	Total Conditioned Air Fan Energy	AHU_Fan_Pwr	0 to 140 kW	SA_Pwr + RA_Pwr
18	Mixed Air Temperature Average	MA_AveDB_Temp	30 to 110 F	(io01.ma1temp + io01.ma2temp) / 2
19	Total System Static Pressure	Tot_System_Stat	0 to 20 in W. C.	(RA_Stat_Pres+SA_Stat_Pres)
20	Conditioned Air Fan Efficiency	Fan_Eff	0 to 1.0 kW/ton	AHU_Fan_Pwr/Tot_Tons
Pumps				
21	Total Pump Energy	Pump_Pwr	0 to 40 kW	CHWP1_Pwr + CWP1_Pwr + CHWP2_Pwr + CWP2_Pwr
22	Pump Efficiency	Pump_Eff	0 to .3 kW/ton	Pump_Pwr/Tot_Tons
System				
23	Total System Cooling Load	Tot_Tons	0 to 450 tons	Ch1_Tons + Ch2_Tons
24	Total System Condenser Load	Tot_CWTons	0 to 450 tons	Ch1CW_Tons + CH2CW_Tons
25	Total Cooling System Energy	Cooling_Pwr	0 to 500 kW	Ch1_Pwr + Ch2_Pwr + CT_Fans_Pwr + AHU_Fan_Pwr + Pump_Pwr
26	Total Cooling System Flow	CHW_Flw	0 to 600 gpm	CHWR_Main_Flw+L2_CHWR_Flw
27	Total Cooling System Efficiency	Cooling_Eff	0 to 3.0 kW/ton	Cooling_Pwr / (Tot_Tons)
Power				
28	Building Watts per Square Foot	main_pwr_wsf	0 to 6 wsf	io05.mainpwr / 98
29	Cooling Load Watts per Square Foot	cooling_wsf	0 to 4 wsf	Cooling_Pwr / 98
30	Plug Load Riser Power	Plug_Riser_Pwr	0 to 400 kW	io06.plgr1pwr + io06plgr2pwr
31	Plug Load Watts per Square Foot	plug_wsf	0 to 3 wsf	(io06.plgr1pwr + io06.plgr2pwr) / 98
32	Lighting Load Riser Power	Light_Riser_Pwr	0 to 400 kW	(io05.lgtr1pwr + io05.lgtr2pwr)
33	Lighting Load Watts per Square Foot	light_wsf	0 to 4 wsf	(io05.lgtr1pwr + io05.lgtr2pwr) / 98

Schematic of IMDS Infrastructure for a Single Building



Enthalpy Wet Bulb Enclosure Layout



A diagram showing an internal view of the enclosure is included in the report on page 3-9.

Equipment Costs

Data Acquisition System (Enflex)	Cost
Host and Main Controller	$2,788.75
Other controllers	$4,153.80
60 VA transformers	$207.00
Network hubs and cables	$258.75
Lonworks adapter	$437.00
GUI/Configuration Software	$690.00
	$8,535.30
Computer System	
PC, Monitor & Peripherals	**$3,938.00**
Sensors	
Cooling System	
Chiller Temperatures (8 Thermistors)	$1,320.00
CT Temperatures (10 Thermistors, 2 EWB enclosures)	$3,079.38
Differential Pressure (8 Sensors, 3 Power Supplies)	$2,939.00
Chiller Power (2 PT's, 4 CT's, 2 shorting terminal)	$900.00
Pump Power (4 PT's)	$1,640.00
Fan Power (2 PT's, 4 CT's, 2 shorting terminal)	$900.00
Flow (5 Sensors and wire)	$14,781.60
	$25,559.98
AHU	
Ambient Air Temperatures (6 Thermistors, 1 EWB	1387.86
Static Pressure (4 sensors)	$1,396.00
Fan Power	$900.00
	$3,683.86
Building Power	
Main Power (1 PT, 3 CT's)	$1,316.00
Lighting Power (2 PT's, 6 CT's, 2 Fuse Block, 1	$1,300.00
Plug Load (2 PT's, 6 CT's, 2 Fuse Block, 1 Disconnect)	$1,300.00
	$3,916.00
Sensors Total	**$33,159.84**
Sensor Calibration	**$8,400.00**
Networking	
ISDN Installation	$277.66
ISDN Annual Usage Charges *	$5,400.00
ISP Installation	$295.00
ISP Annual Usage Charges	$2,940.00
	$8,912.66
Grand Total	**$62,945.80**

*Estimated. Actual cost will vary with usage.
Note: Costs listed here represent actual expenditures by LBNL and Supersymmetry - market costs may vary.
Equipment listed includes what is currently installed at the building.

Appendix D. IMDS Findings Report Log (version 6/30/98)

Information Monitoring and Diagnostic System
Findings Report -- 160 Sansome

Date Reported:	**Time:**	**By: Fred Glen ________**
Finding:		
How was this discovered:		
Is this a problem?		
What type of graph did you use? Please print and attach.		
Which points were viewed?		
Time interval: 1:00 0:30 0:20 0:15 0:12 0:10 0:06 0:05 0:04 0:03 0:02 0:01		
Time period/Dates:		
Suggested plan for action:		
Expected result of action:		
Date of Action:	**Time:**	**By: Fred Glen ________**
Action Taken:		
How did you confirm the result? Please print any graphs used.		